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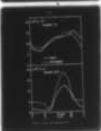
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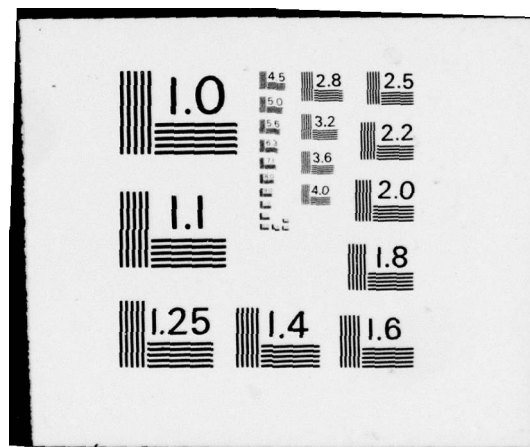
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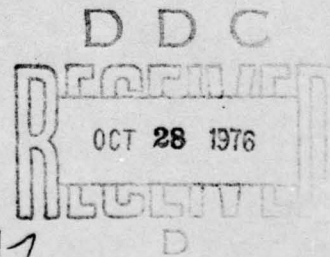
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In the late afternoon the TEC is depleted at all seasons as a response to the substorms.

In the night enhancements are observed due to the precipitation of substorm-injected electrons. These enhancements are very large during winter. During summer other factors cause a depletion of TEC. At sunspot maximum the net result is a depletion and at sunspot minimum an enhancement.

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Paper: Behavior of auroral zone total electron content during substorms.

Abstract:

The auroral zone total electron content TEC as computed from the ATS-3 Faraday-rotation shows systematic changes during magnetic activity. These changes depend upon local time, season, sunspot-cycle and the prehistory of the magnetic activity.

During summer and equinox the daytime TEC both shows a positive and negative phase, which probably are related to the prehistory of the magnetic activity. During winter the daytime TEC is dominated by enhancements as responses to the substorms. The magnitude of these enhancements is determined by the activity prior to sunrise. Thus if the activity is low prior to sunrise, the substorms during the subsequent day cause the TEC to blow up. In contrast if the pre-sunrise activity is high the daytime TEC is similar to the quiet time level.

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Introduction.

The behavior of the auroral oval F region ionization during magnetic activity is of special interest. This is so, because the electric fields, joule heating and particle precipitation which influence the neutral atmosphere and ionosphere have their maxima in the auroral oval.

By recording the Faraday-rotation of a geostationary satellite signal the total ionospheric electron content, abbreviated TEC, can be monitored almost continuously. TEC is simply proportional to the total Faraday-rotation.

Since 1969 the geostationary satellite ATS3 has been recorded at the auroral zone station Narssarssuaq, Greenland. Data from 1970 and 1971 have not been reduced, but the data from 1969 and recent data allow us to compare sunspot maximum and sunspot minimum behavior. The ATS3 signal crosses the F-region at 63° invariant latitude. During the night this latitude is within the main ionospheric trough. During the day the F-region at 63° shows mid-latitude behavior. With increasing magnetic activity the oval expands to lower latitudes such that oval conditions prevail at night. At noon TEC still shows mid-latitude behavior during very disturbed periods. First we discuss the statistical behavior of TEC with increasing magnetic activity. Next we go back to the original data and look for this statistical behavior of TEC in individual days. This is important because the statistical analysis only takes into account the instantaneous level of activity. Thus the prehistory of magnetic activity as well as the onset time (local time) of the activity is disregarded in the statistical analysis. Finally we discuss the proposed influences of electric fields, neutral winds and electron precipitation.

Statistical results.

To see the influence of magnetic activity all 3 hour pieces of the TEC curve are sorted according to the simultaneous Kp-indices. To see the seasonal variation, the data are collected in groups of 27 days. This is a short period compared to the seasonal variations. The 27-day period is chosen, because it is equal to the periodicity of the magnetic activity. Thus each group is expected to contain a typical distribution of quiet and disturbed days. Furthermore since the solar UV-flux also has a 27-day period the effect of the varying UV-flux is expected to be averaged out within each group of 27 days.

Figure 1 shows the daily and seasonal variation of TEC at 63° invariant latitude. It is a contour-map of quiet time ($K_p = 0,1$) TEC. At the top are indicated the TEC levels (in units of 10^{16} el m^{-2}) of the different shadings. The + and - show the changes of TEC, when the magnetic activity goes up. These changes are discussed later. The horizontal axis is cor-

rected geomagnetic local time. Corrected geomagnetic midnight takes place at 02 UT. Local solar midnight is at 03.30 UT. The vertical axis is season starting with May 1972 and terminating with March 1975. The contour map has been constructed by combining the median daily curves of quiet-time TEC from each group of 27 days.

Behavior of quiet time TEC.

The large white areas of figure 1 show the extent in local time and season of the very low TEC-values. Since the quiet winter night TEC is constant for several hours and also is the lowest of all observed TEC values it is probably also the bottom of the latitudinal profile during winter night. This minimum in both longitude and latitude is identified as the main ionospheric trough. Whether the daily minimum during summer night is also the minimum of a latitudinal profile is not known. It is probably so, when considering the K_p -value ($=0,1$) and the invariant latitude ($=63^\circ$, $L=5$). The highest TEC values are observed during the summer daytime. In contrast to the TEC data from 1969, (Mikkelsen, 1972) which showed a pronounced winter anomaly, the ratio between winter and summer content is reversed at sunspot minimum. This is similar to f_oF_2 behavior. (King and Smith, 1968).

Changes of TEC in connection with magnetic activity.

Like the contour map shown in figure 1 contours of TEC have also been constructed for higher levels of magnetic activity. In figure 1 we have indicated the sign of the difference TEC-median ($K_p > 4$) - TEC-median ($K_p = 0,1$). Because of incomplete data the transition from positive to negative areas is not well defined in a few places. This is indicated by stippled lines.

The significant changes of TEC can be listed as follows:

- 1) In the late afternoon after 18 CGLT TEC is lower during disturbed than during quiet conditions. Looking at the upper quartile of disturbed TEC it is also lower than the lower quartile of quiet TEC values at this local time. This

means that most disturbed days show a depletion of TEC after 18 CGLT. This is the case for all seasons and independent of the TEC level prior to the depletion.

2) During winter the late afternoon depletion is followed by an enhancement due to precipitating electrons. (Mikkelsen 1975). This winter night enhancement lasts until sunrise for very disturbed conditions as demonstrated by figure 2. The onset of the afternoon depletion is probably due to the onset of the mechanisms, which form the main ionospheric trough. Subsequently the auroral oval expands equatorward into the trough and fills it up with ionization. This is not very clear from figure 1 and 2, but when considering only moderately disturbed days ($K_p=2,3$) a clear separation can be seen between the depletion and subsequent enhancement of TEC.

3) During summer the depletion which started in the late afternoon extends into the night. Thus an enhancement due to electron precipitation, which is centered at corrected geomagnetic midnight, is not evident. During 1969 (Mikkelsen, 1972) at sunspot maximum, the TEC showed a more pronounced depletion during night. Figure 1 shows, that there is a gradual change from a negative to a positive response of TEC when approaching the sunspot minimum.

4) The winter day-time TEC shows a very pronounced enhancement at disturbed days. This is also a very significant effect, since the lower quartile of the disturbed TEC values is also bigger than the upper quartile of the quiet TEC values. This enhancement is seen during all years both at the maximum (Mikkelsen, 1972) and the minimum of the sunspot cycle.

5) During the summer and equinox day changes which are repeatable from year to year can be seen in figure 1. In the equinox day the TEC goes down. The summer day both shows a positive and negative phase. The statistics shows, that the quartiles of quiet and disturbed TEC are not separated. Going back to the individual days it means, that a very variable behavior is seen.

Dependence of TEC upon prehistory of magnetic activity and local time onset of activity.

Mendillo (1973) has found a systematic behavior of the mid-

latitude TEC during sudden commencement storms. In many cases TEC shows a positive phase at the first day of the storm and a negative phase at the subsequent days. According to Mendillo (1973) the positive phase or enhancement of TEC which occurs near dusk is only observed, when a nearby magnetic observatory shows a positive bay, the signature of an eastward ionospheric current. Furthermore if the storm starts at such a local time, that the magnetic observatory encounters a strong negative bay (westward electrojet) as the first event of the storm, the positive bays on the subsequent days do not have connected with them TEC enhancements. We have looked for the same pattern in the auroral zone. Until now only the winter data have been analyzed. The summer and equinox (apart from a few cases) await a future analysis.

The winter day time TEC is enhanced during magnetic activity. Figure 2 shows, that the enhancement starts at sunrise. TEC continues to grow at a bigger rate than during quiet conditions until the maximum is reached. The time of maximum is coincident with the quiet time maximum. Shortly after the maximum is passed, TEC decays more rapidly than during quiet conditions, which leads to the afternoon depletion. This median behavior of TEC is the same in the three winters studied, that is 72/73, 73/74 and 74/75.

Going back to the original data especially the winter 72/73 shows many days, where TEC goes to very high values. It is common to these days, that the Kp-index increases during the hours 6-15 UT. The median behavior of Kp is such, that Kp equals 1, 2, and 4 in the three-hour intervals 6-9, 9-12, and 12-15 respectively. To test the relationship, we have searched for all days having this development of Kp-index. Indeed there are not more days, than those, which show the very big TEC-values. Thus, if Kp is low during the hours 6-12 UT, the auroral oval following the normal diurnal pattern migrates northward. This means, that the separation between the oval and the F-region observed is big, such that the F-region is left untouched of the physical processes active along the oval. In that case a subsequent in-

crease of magnetic activity during the day-time causes the TEC to blow up. There is no dependence of TEC upon the very long prehistory of magnetic activity. The pronounced TEC enhancements discussed here are not related to sudden-commencement storms.

If on the contrary the magnetic activity is high during the hours 6-12 UT, TEC the following day shows a smaller enhancement as a response to magnetic activity. If the period 6-12 UT is very disturbed TEC remains at the quiet time level the following day. (During the late afternoon the depletion is still present). The above description applies to the winters 72/73 and 73/74. The behavior of TEC during the winter 74/75 does not fit into the systematics described above. The winter is more disturbed. Kp is equal to or greater than 40 20% of the time. During the winters 72/73 and 73/74 this is only the case 10% of the time. Examining the individual days, the long periods of high activity both show positive and negative days. In contrast to the two winters 72/73 and 73/74 the „negative days„ during 74/75 are definitely below the quiet level. There is no simple clue in the Kp-index to these positive and negative days.

Discussion of proposed mechanisms influenizing the auroral zone TEC.

The seasonal variation of the ionospheric substorm is believed to be caused by a seasonal enhancement of the ratio $n(O)/n(N_2)$ from summer to winter. (Mayr et al., 1976). This is supported by Pröls and Zahn (1974), who find a good correlation between the relative changes of f_oF2 and the relative changes of the ratio $n(O)/n(N_2)$ during ionospheric storms. Theoretically Park and Banks (1975) have computed that Nmax goes down by a factor 2, when the concentration of N_2 is enhanced by a factor 5. Thus the low abundance of N_2 during winter means, that the processes which enhance TEC may dominate the loss due to charge exchange with N_2 both at quiet and disturbed conditions. According to Mayr et al. 1976 the reversal of the winter anomaly at sunspot minimum may be caused by a relative enhancement of

$n(O_2)/n(O)$ from summer to winter - at sunspot minimum. Although this enhancement of O_2 can remove the winter anomaly it is not able to create a negative phase during the winters 72/73 and 73/74. Whether the negative days of the winter 74/75 are caused by an extra high abundance of O_2 or by the particularly high magnetic activity during that winter can not be decided here.

Considering the foregoing discussion of the seasonal variation of the thermospheric composition it is tempting to suggest, that the positive phase of the ionospheric substorm during the winter day (which includes the dusk-effect) is created by the same mechanism, which causes the positive dusk effect at midlatitudes as described by Mendillo (1973).

Many authors have suggested that the positive phase of the ionospheric substorm is caused by a lift of the plasma to greater altitudes, where the recombination is slower. Horizontal transport may also cause changes of TEC, if horizontal gradients of the plasma are moved past the observation point. But such effects can not explain the positive phase. For example, the quiet time latitudinal TEC gradients shown by Mendillo and Klobuchar (1975) are too small to explain the enhancements even if we imagine a very big (and unrealistic) poleward plasma convection at midlatitudes. The same can be seen from latitudinal profiles of TEC obtained from the polar orbiting satellite S66 (Mikkelsen, 1971).

A downward flow of plasma would also increase the TEC. This mechanism is active south of the plasmapause, but according to Park and Banks (1975) it is only a minor modification to the day time F-region.

Thus the only possible mechanism to explain the positive phase is to lift the plasma to greater altitudes. This can be done by southward neutral winds or by a northward plasmaconvection. The latitudinal profiles published by Mikkelsen (1971) show that the dusk enhancement terminates at a high latitude, where TEC drops by a sharp gradient to a low value. We can not explain this behavior, but we can incorporate the different mechanisms proposed into a model. The relative importance of the equatorward neutral winds and the poleward plasmaconvection may vary with local time. The neutral winds originate from a high pressure region along the oval created by Joule heating and/or particle precipitation. Schunk and Banks (1975b) suggest that N_2 molecules are excited $N_2 \rightarrow N_2^*$ in the oval. The neutral winds blow these excited molecules equatorward. Because the charge exchange reaction

$O^+ + N_2 \rightarrow NO^+ + N$ is more rapid, when N_2 is excited, the O^+ ions are depleted. This process would prevent the creation of the enhancement. Therefore, if it exists, the N_2 molecules must be removed before the neutral wind reaches the region of the observed enhanced TEC.

There is another process proposed, which could explain the steep slope, which is the poleward termination of the enhancement. According to Schunk et al. (1975a), the process $O^+ + N_2 \rightarrow NO^+ + N$ is speeded up, if the relative speed of the two reactants O^+ and N_2 is enhanced. This can be done by neutral winds (moving N_2) or by electric fields moving the plasma (of which O^+ is part). The neutral winds are too small to be of importance, but rapid plasmaconvection has a very drastic effect. We have integrated the electron density profiles shown by Schunk et al. (1975) to find that TEC is decreased by a factor 2, when the electric field is shifted from 0 to 100 mv/m. It is well known, that the regions of plasma return flow expands equatorward and the plasma speed is also enhanced in connection with magnetic activity. This means, that the F-region at 63° invariant latitude comes in touch with the plasma-return flow at an earlier local time of the afternoon during disturbed conditions. This could explain the late afternoon depletion of TEC. Recently Brinton (1975) has measured, that the concentration of NO^+ goes up within regions of enhanced plasma flow. This further supports the proposed mechanism.

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References.

- Brinton, H.C., In situ measurements of plasma drift velocity and enhanced NO^+ in the auroral electrojet by the Bennett mass spectrometer on AE-C, Geophys. Res. Letters, 2, 243, 1975.
- King, J.W. and P.A. Smith, The seasonal anomaly in the behavior of the F_2 layer critical frequency, J. Atmos. Terr. Phys., 30, 1707, 1968.
- Mayr, H.G., P. Bauer, H.C. Brinton, and L.H. Brace, Diurnal and seasonal variations in atomic and molecular Oxygen inferred from atmosphere Explorer-C, Geophys. Res. Letters, 3, 77, 1976.
- Mendillo, M., A study of the relationship between geomagnetic storms and ionospheric disturbances at midlatitudes, Planet. Space Sci., 21, 349, 1973.
- Mendillo, M., and J.A. Klobuchar, Investigations of the ionospheric F-region using multistation total electron content observations, J. Geophys. Res., 80, 643, 1975.
- Mikkelsen, I.S., Knee of total electron content and scintillation boundary, Danish Meteorological Institute, Geophysical Papers, R-21, 1971.
- Mikkelsen, I.S., Seasonal, diurnal and magnetic dependence of ionospheric total electron content at 63° invariant latitude. 1972, available through the author.
- Mikkelsen, I.S., Enhancements of the auroral zone ionization during substorms, Planet. Space Sci., 23, 619, 1975.
- Park, C.G., and P.M. Banks, Influence of thermal plasma flow on the daytime F_2 layer, J. Geophys. Res., 80, 2819, 1975.
- Prölss, G.W., and U. von Zahn, Esro 4 gas analyzer results 2, Direct measurements of changes in the neutral composition during an ionospheric storm, J. Geophys. Res., 79, 2535, 1974.
- Schunk, R.W., W.J. Raitt, and P.M. Banks, Effect of electric fields on the day-time high-latitude E- and F-region, J. Geophys. Res., 80, 3121, 1975a.
- Schunk, R.W., and P.M. Banks, Auroral N_2 vibrational excitation and the electron density trough, Geophys. Res. Letters, 2, 239, 1975b.

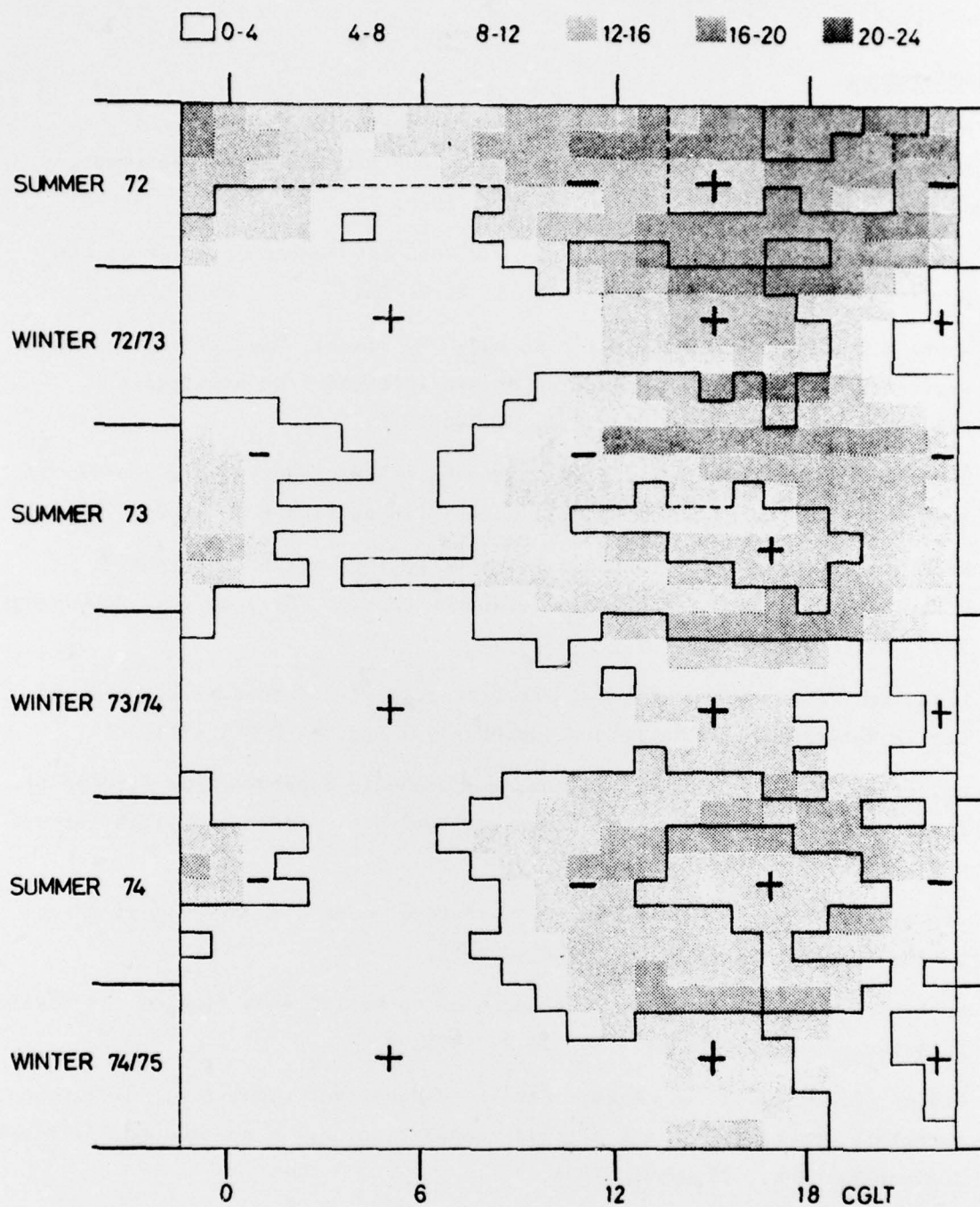


Figure 1. Contours of quiet time auroral zone TEC in units of $10^{16} \text{ el m}^{-2}$. Horizontal axis is corrected geomagnetic local time and vertical axis shows seasons. + and - indicate changes during ionospheric substorms.

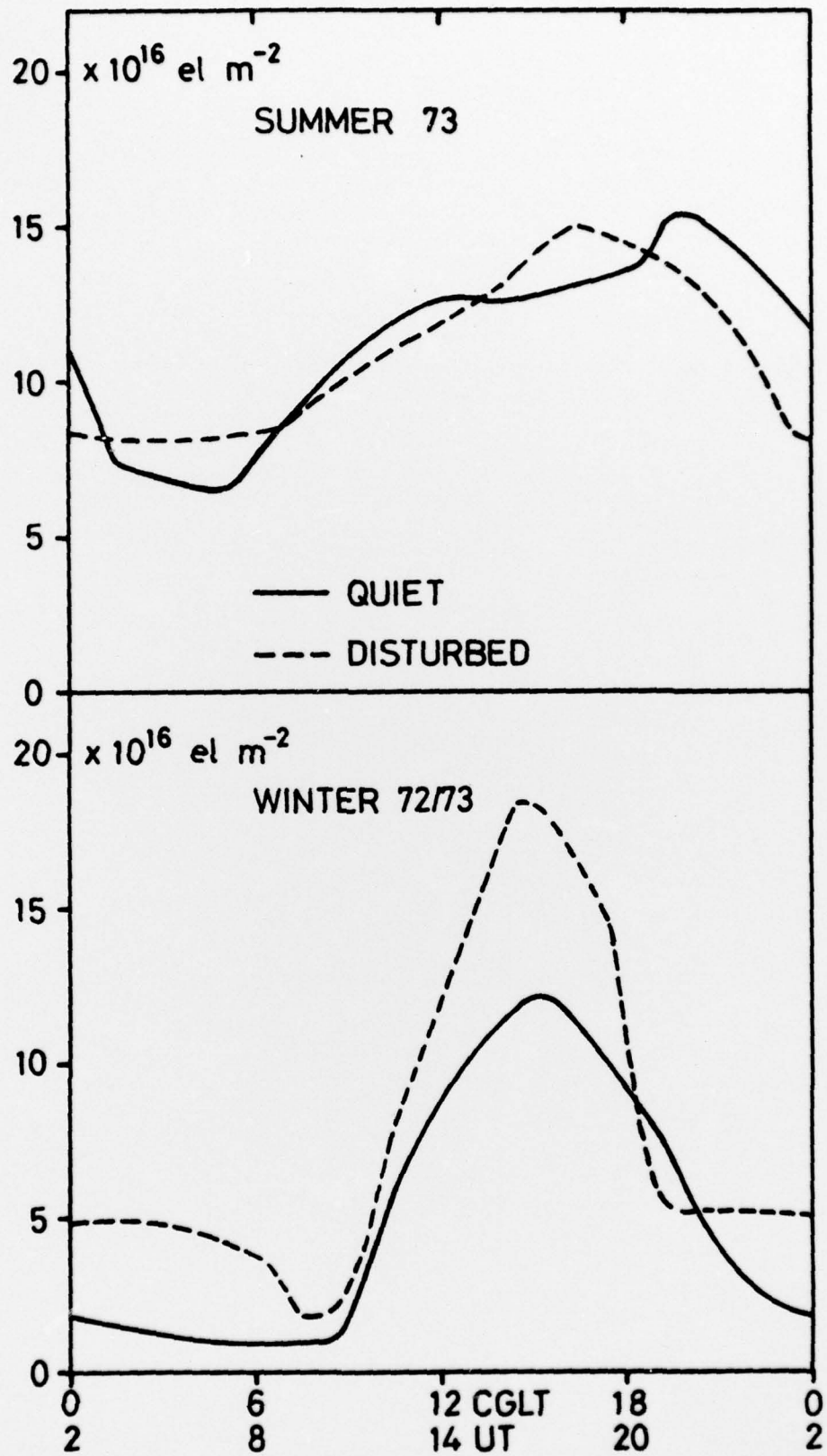


Figure 2. Quiet and disturbed TEC.